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MULTIBAND MULTIMODE COMMUNICATION ENGINES

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MULTIBAND MULTIMODE COMMUNICATION ENGINES

Cross references to related applications

This application is related to U.S. Patent Application Serial No. 10/118,657, filed April 8, 2002, and assigned to the assignee of the present application. This application is also related to patent applications Docket No. 944-005-022 and Docket No. 944-005-023 assigned to the assignee of the present application and filed even date herewith.

Field of the Invention

The present invention relates generally to front-end topology and, more particularly, to front-end arrangement for multiband and/or multimode mobile cellular handset electronics.

Background of the Invention

The term "front-end" as used in this disclosure, means the components and functions between the antennas and the power amplifiers or RF-ASIC (radio frequency application specific integrated circuit), but some front-end modules may also include power amplifiers. The front-end in multiband, multimode engines, especially those that are designed to meet the requirement of MIMO (multiple-input, multiple-output) and/or diversity functionality, is usually very complex in construction and design. Because the front-end generally comprises many switches, it consumes a significant amount of electrical current and needs many control lines. MIMO functionality is required in new and future mobile terminals and, initially, Rx MIMO is prioritized because the downlink data rate is more important than the uplink counterpart in mobile communications. Essentially, Rx MIMO requires more than one Rx path to be provided on a particular band of operations. The outputs of these paths are then monitored and combined to give an enhanced data rate. The antenna feed to each of these paths is independent from each other.

Currently, a GSM/W-CDMA multimode engine is designed to have a separate GSM antenna and a separate W-CDMA antenna. A W-CDMA antenna is connected to a duplexer that has a passband filter for both the Rx and Tx paths of the W-CDMA mode. The GSM antenna is connected to an antenna switch module that typically first separates the 1GHz frequencies from the 2GHz bands using a diplexer or the like. The Rx and Tx

paths of each frequency range are then separated by switches. The antenna switch module often also includes harmonic filtering for the power amplifier outputs and may include surface-acoustic wave (SAW) filters to provide filtering for the Rx paths. A typical block diagram of a typical front-end is shown in Figures 1a and 1b. As shown in Figure 1a, the GSM module includes four sections: 1GHz GSM Rx section, 1GHz GSM Tx section, 2GHz GSM Rx section and 2GHz GSM Tx section. The 1GHz GSM Rx section includes an 869-894MHz Rx path **110**, and the 925-960 MHz Rx path **130**. The 1GHz GSM Tx section, collectively denoted as path **150**, includes two frequency bands of 824-849MHz and 880-905MHz. The 869-894MHz Rx path **110** includes a filter **116** connected between ports **112** and a balun **122**. The 925-960MHz Rx path **130** includes a filter **136** connected between ports **132** and a balun **142**. The balun functionality can be incorporated into the filters **116** & **136** depending on the filter technology. The Rx paths **110** and **130** are joined at a common node **410**. These Rx paths are also joined with the port **152** of the 824-849/880-905MHz Tx path **150** at a node **412** via a matching element **80**. Here PIN diodes **42** and **44** are used for Tx-Rx switching. Alternatively, other switch technologies can be also used e.g. CMOS or GaAs p-HEMTs (Pseudomorphic High Electron Mobility Transistor). However, by using the CMOS and p-HEMT switches, the arrangement of biasing and matching elements will be slightly modified.

The 2GHZ Rx section includes a 1805-1880MHz Rx path **220**, commonly referred to as the 1800GSM mode, and the 1930-1990 MHz Rx path **240**, commonly referred to as the 1900GSM mode. The 2GHz GSM Tx section, collectively denoted as path **260**, includes two frequency bands of 1710-1758MHz and 1850-1910MHz. The 1805-1880MHz Rx path **220** includes a filter **226** connected between ports **222** and a balun **232**. The 1930-1990MHz Rx path **240** includes a filter **246** connected between ports **242** and a balun **252**. The Rx paths **220** and **240** are joined at a common node **414** with matching circuits or devices **84**, **86**. These Rx paths are also joined with the port **262** of the 1710-1758/1850-1910 MHz Tx path **260** at a node **416** via a matching element **82**. Here PIN diodes **46**, **48** are used for Tx-Rx switching. The 1GHz and 2GHZ parts are connected to a common feed point **418** of the GSM antenna **10** through a diplexer **30**, which comprises harmonic filters **32**, **34** for the Tx paths **150** and **260**.

In Figure 1b, the W-CDMA module has two paths: a 2110-2170 MHz Rx path **320** and a 1920-1980 MHz Tx path **340**. The Rx path **320** includes a filter **326** connected between ports **322** and a balun **332**. However, the balun can also be after the filter and

external to the duplexer. The 1920-1980 Tx path **340** has a passband filter **346** and a port **342**. The Rx path **320** is joined with the Tx path **340** at a node **420** and a common W-CDMA antenna **20** via a matching element **90**.

To use one antenna for the GSM mode and one antenna for the W-CDMA mode, it is required that the front-end includes matching devices **80**, **82**, **84**, **86** and other necessary components for matching and biasing, depending also on the switch technology chosen, to separate the 1805-1880MHz GSM Rx path **220** and the 1930-1990MHz GSM Rx path **240**. The front-end architecture is complex and the additional losses in these reception paths occur.

It is advantageous and desirable to provide a front-end architecture where the complexity can be reduced.

<u>Summary of the Invention</u>

The present invention reduces the complexity of frond-end design by combining one or more 2GHz GSM Rx paths with one or more W-CDMA paths. With such a combination, the number of matching elements and the switching components can be reduced or even eliminated. As a result, the current consumption and the losses in the front-end engines can also be reduced, and fewer control lines are required.

Thus, according to the first aspect of the present invention, there is provided a transceiver front-end for use in a portable communication device, the communication device having a first antenna and a second antenna electrically separated from the first antenna, the transceiver front-end having a plurality of signal paths for conveying communication signals in the communication device, including at least a first signal path for conveying a communication signal in a first frequency band, and a second signal path for conveying a communication signal in a second frequency band, which is at least partially overlapped with the first frequency band, said front-end comprising:

a first feed point, operatively connected to the first antenna, for conveying the communication signals in the first signal path in the communication device via the first antenna; and

a second feed point, operatively connected to the second antenna, for conveying the communication signals in the second signal path in the communication device via the second antenna so that the communication signals in the partially overlapped frequency bands are conveyed via different antennas.

The first frequency band substantially covers a frequency range of 1930 MHz to 1990 MHz, and the second frequency band substantially covers a frequency range of 1920 MHz to 1980 MHz.

Alternatively, the first frequency band substantially covers a frequency range of 1850 MHz to 1910 MHz, and the second frequency band substantially covers a frequency range of 1805 MHz to 1880 MHz.

The transceiver front-end further comprising

a first module, operatively connected to the first feed point, for disposing the first signal path for transmitting the communication signals, and

a second module, operatively connected to the second feed point, for disposing the second signal path for receiving the communication signals.

The second module further comprises a third signal path for reception in a third frequency band different from the second frequency band.

The third frequency band substantially covers a frequency range between 2110 MHz and 2170 MHz.

The communication signals in the first and second frequency bands are transmitted in a GSM mode, and the communication signals in the third frequency band are transmitted in a W-CDMA mode.

The second module further comprises a fourth signal path for transmission substantially in a frequency range of 1920 MHz to 1980 MHz in a W-CDMA mode.

The first module further comprises a fifth signal path for reception substantially in a frequency range of 1930 MHz to 1990 MHz.

Alternatively, first frequency band substantially covers a first frequency range of 1710 MHz to 1785 MHz for transmission, and a second frequency range of 1850 MHz to 1910 MHz for transmission, and the second frequency band substantially covers a third frequency range of 1805 MHz to 1880 MHz for reception. The first signal path comprises:

a first end;

a second end operatively connected to the first feed point;

a first passband filter disposed between the first end and the second end for filtering the communication signals in the first frequency range;

a second passband filter disposed in parallel to the first passband filter between the first end and the second end for filtering the communication signals in the second frequency range;

a first matching means operatively connected to the first end; and a second matching means operatively connected to the second end.

The first feed point is also connected to a third signal path for receiving communication signals substantially in a frequency range of 1930 MHz to 1990 MHz.

Advantageously, a switching circuit operatively connected to first feed point for providing a switching function between the first signal path and the third signal path. The switching means comprises

a first PIN diode connected in series to the first signal path,

a second PINdiode connected to the third signal path in a shunt configuration, and a phase shifting means connected between the first and second PIN diodes.

Alternatively, the switching means comprises:

a first solid state switch connected in series to the first signal path, and

a second solid state switch connected in series to the third signal path, wherein the communications signals received in the third signal path are transmitted in a GSM mode.

Advantageously, the first feed point is further connected to signal paths for transmission and reception of communication signals in a GSM mode operating in a frequency range lower than 1000 MHz.

Alternatively, the first frequency band substantially covers a frequency range of 1805 MHz to 1880 MHz for transmitting the communication signals, and

the second frequency band substantially covers a frequency range of 1850 MHz to 1910 MHz for receiving the communication signals, and wherein

the second feed point is also connected to a third signal path for reception of communication signals substantially in a frequency range of 1930 - 1990 MHz.

Alternatively, the first frequency band substantially covers a frequency range of 1805 MHz to 1880 MHz for transmitting the communication signals, and

the second frequency band substantially covers a frequency range of 1850 MHz to 1910 MHz for receiving the communication signals, and wherein

the first feed point is also connected to a third signal path for transmission of communication signals substantially in a frequency range of the 1920 MHz – 1980 MHz.

Advantageously, the first feed point is also connected to a fourth signal path for transmission of communication signals substantially in a frequency range of the 1920 MHz – 1980 MHz. The first frequency band also covers a further frequency range substantially between 1710 MHz to 1785 MHz. The second feed point is also connected to a fifth signal path for reception of communication signals in a frequency range substantially between 2110 MHz and 2170 MHz. The first feed point is also connected to further signal paths for transmission and reception of communication signals in a GSM mode operating in a frequency range lower than 1000MHz.

Advantageously, the portable communication device further comprises a third antenna, said transceiver front-end further comprising a third module having a third feed point operatively connected to the third antenna, the third feed point electrically separated from the first and second feed point, wherein the third module further comprises

at least one further signal path for receiving a communication signal substantially in one of the frequency ranges: (1805 - 1880 MHz), (1930 - 1990 MHz), and (2110 - 2170 MHz).

According to the second aspect of the present invention, there is provided a method for reducing reception loss in a portable communication device, the communication device having

a first antenna,

a second antenna electrically separated from the first antenna, and

a transceiver front-end for conveying communication signals in the communication device, wherein the transceiver front-end comprises:

a first feed point, operatively connected to the first antenna,

a second feed point, operatively connected to the second antenna, and

a plurality of signal paths, including at least a first signal path for conveying a communication signal in a first frequency band, and a second signal path for conveying a communication signal in a second frequency band, which is at least partially overlapping with the first frequency band, said method comprising the steps of:

operatively connecting the first signal path to the first feed point, and

operatively connecting the second signal path to the second feed point, so that the communication signals in the partially overlapped frequency bands are conveyed via different antennas.

The first frequency band substantially covers a frequency range of 1930 MHz to 1990 MHz, and the second frequency band substantially covers a frequency range of 1920 MHz to 1980 MHz.

Alternatively, the first frequency band substantially covers a frequency range of 1850 MHz to 1910 MHz, and the second frequency band substantially covers a frequency range of 1805 MHz to 1880 MHz.

Alternatively, the first frequency band substantially covers a frequency range of 1850 MHz to 1910 MHz for transmission of the communication signals, and the second frequency band substantially covers a frequency range of 1805 MHz to 1880 MHz for reception of the communication signals, and wherein the reception is also carried out in a third signal path in a frequency range substantially between 2110 MHz and 2170 MHz. The method further comprises the step of:

operatively connecting the third signal path to the second feed point.

Advantageously, the transmission is also carried out in a fourth signal path in a frequency range substantially between 1930 MHz and 1990 MHz. The method further comprises the step of:

operatively connecting the fourth signal path to the first feed point.

Alternatively, the first frequency band substantially covers a frequency range of 1850 MHz to 1910 MHz for transmission of the communication signals, and the second frequency band substantially covers a frequency range of 1805 MHz to 1880 MHz for reception of the communication signals, and wherein the reception is also carried out in a third signal path in a frequency range substantially between 2110 MHz and 2170 MHz. The method further comprises the step of:

operatively connecting the third signal path to the first feed point.

Advantageously, the transmission is also carried out in a fourth signal path in a frequency range substantially between 1930 MHz and 1990 MHz. The method further comprises the step of:

operatively connecting the fourth signal path to the second feed point.

According to the third aspect of the present invention, there is provided a portable communication device, comprising:

a first RF antenna;

a second RF antenna electrically separated from the first antenna; and

a transceiver front-end having a plurality of signal paths for conveying communication signals in the communication device, including at least a first signal path for conveying a communication signal in a first frequency band, and a second signal path for conveying a communication signal in a second frequency band, which is at least partially overlapped with the first frequency band, wherein the front-end further comprises:

a first feed point, operatively connected to the first antenna, for conveying the communication signals in the first signal path in the communication device via the first antenna; and

a second feed point, operatively connected to the second antenna, for conveying the communication signals in the second signal path in the communication device via the second antenna so that the communication signals in the partially overlapped frequency bands are conveyed via different antennas.

Advantageously, the front-end further comprises

a first module, operatively connected to the first feed point, for disposing the first signal path, and

a second module, operatively connected to the second feed point, for disposing the second signal path. The first frequency band substantially covers a frequency range of 1920 MHz to 1980 MHz, and the second frequency band substantially covers a frequency range of 1930 MHz to 1990 MHz.

Alternatively, the first frequency band substantially covers a frequency range of 1805 MHz to 1880 MHz, and the second frequency band substantially covers a frequency range of 1850 MHz to 1910 MHz.

The communication device can be a mobile phone, a communicator device or the like.

The present invention will become apparent upon reading the description taken in conjunction with Figures 2a to 8.

Brief Description of the Drawings

Figure 1a is a block diagram illustrating a GSM part of a prior art front-end module.

Figure 1b is a block diagram illustrating a W-CDMA part of the same prior art front-end module.

Figure 2a is a block diagram illustrating a GSM part of an embodiment of the front-end module, according to the present invention.

Figure 2b is a block diagram illustrating a mixed GSM/W-CDMA part of the front-end module of Figure 2a.

Figure 2c is a block diagram illustrating a different switching arrangement in the GSM upper band section.

Figure 2d is a block diagram illustrating another different switching arrangement in the GSM upper band section.

Figure 3 is a block diagram illustrating a different embodiment of the GSM part of the front-end module, according to the present invention.

Figure 4a is a block diagram illustrating a mixed GSM/W-CDMA 2GHz Tx module in combination with a 1GHz GSM Tx/Rx module, according to the preferred embodiment of the present invention.

Figure 4b is a block diagram illustrating a mixed GSM/W-CDMA 2GHz Rx module, according to the preferred embodiment of the present invention.

Figure 4c is a block diagram illustrating a different switching arrangement in the GSM upper band signal path and the W-CDMA path.

Figure 4d is a block diagram illustrating filters with a balance function being used in the receive module of Figure 4b.

Figure 4e is a block diagram illustrating another mixed GSM/W-CDMA module, where the frequency separation between any two bands is at least 20MHz.

Figure 4f is a block diagram illustrating a mixed GSM/W-CDMA module to be used together with the module of Figure 4d in a transceiver front-end.

Figure 5a is a schematic representation showing the Tx-Rx antenna isolation in GSM/W-CDMA front-end, according to the present invention.

Figure 5b is a frequency chart showing the overlapping in GSM and W-CDMA frequencies.

Figure 6a is a block diagram illustrating the use of switches to solve the cross-band isolation problem in the GSM/W-CDMA 2GHz Rx module in a transceiver front-end.

Figure 6b is a block diagram illustrating the use of low noise amplifier to solve the cross-band problem in the GSM/W-CDMA 2GHz Rx module in a transceiver front-end.

Figure 7 is a block diagram illustrating two receive modules for use in a MIMO/diversity receiver.

Figure 8 is a schematic representation showing a mobile terminal having a transceiver front-end, according to the present invention.

Detailed Description of the Invention

The upper (2GHz) GSM band Rx and Tx performance in a multiband, multimode mobile terminal (or a communicator device and the like) can be improved by relocating some of the GSM and W-CDMA paths in the front-end of the engine. The mobile terminal **1** is schematically shown in Figure 8, which shows a transceiver front-end **2** comprising a first module **4** operatively connected to an antenna **10**, and a second module **8** operatively connected to an antenna **20**.

According to one embodiment of the present invention, the 1800GSM Rx (1805-1880MHz) is moved from the antenna switch to the W-CDMA duplexer. As shown in Figure 2a, the 2GHz part of the GSM module has only one Rx path **240**: 1900GSM Rx (1930-1990 MHz). As such, the matching elements **84** and **86** (see Figure 1a) can be eliminated. The 1800GSM Rx path **220** shares the upper band antenna **20** of the W-CDMA module, as shown in Figure 2b. Because of the different operation modes between the W-CDMA duplexer (Rx path **320** and Tx path **340**) and the GSM, the 1800GSM Rx path **220** can be directly connected to the node **422**, without the need for switches. Only one matching circuit **92** is used to match one of the filters. This arrangement reduces the losses of this specific Rx band up to 2dB due by avoiding the losses caused by the switches for Tx-Rx switching and the diplexer **30** or the like (see Figure 1a). It should be noted that the switching as shown in Figure 2a is accomplished by PIN diodes in a series **(48)** /shunt **(46)** configuration, requiring a $\lambda/4$ transmission line or a 90 degree phase shifter **(82)**. However, there are alternatives: both of the diodes could be in series **(48, 54)** as shown in Figure 2c. In this case, they also draw current when the transceiver front-end is operated in the Rx mode. The diodes can also be replaced by CMOS switches **72, 74**, p-HEMT, MEMS switches or the like, as shown in Figure 2d. These switches have a very low control current. The usage of sufficiently linear switches in the TX branch **(260)** would make it possible to place the switches **46, 48** and **54** between the antenna and the upper band Tx filter **34** (also used to diplex). This would reduce the losses in the Rx

branch **240**. A good candidate for such switches would be CMOS on SOI (Silicon On Insulator), for example.

A further improvement for reducing the losses of the 1900GSM Rx and the 1800 & 1900GSM Tx can be realized by using separate passband filters in the (1710-1758)/(1850-1910) GSM Tx path **260**. As shown in Figure 3, a separate matching circuit **270** and a separate passband filter **266** are used for the 1800GSM Tx (1710-1785MHz), and a separate matching circuit **272** and a passband filter **268** are used for the 1900GSM Tx (1850-1910MHz). As such, the switching elements **46, 48** and **82** (see Figure 2a) and the harmonic filter **34** are eliminated and replaced by selective Tx passband filters **266, 268.** These two passband filters are matched at both ends with circuits **270, 272,** which are passive elements that can be integrated into the module, for example. The removal of the switches and the diplexer/harmonic filter renders it possible to match all three filters to one single antenna feed point **510** without switching. In this arrangement, the 1900GSM Rx filter **246** and the corresponding 1900GSM Tx filter **268** act like a duplexer. Thus, insertion loss can be reduced.

Moreover, the 1920-1980MHz W-CDMA path **340** in the Figure 2b and the 1900GSM Rx path **240** in Figure 3 can change places, as shown Figures 4a and 4b. As shown in Figure 4a, the 1920-1980MHz W-CDMA Tx path **340** is directly connected to the antenna feed point **510** without the need of the matching element **92** (see Figure 2b). As shown in Figure 4b, although there are three Rx paths **220, 240, 320** connected to the antenna **20** with one antenna feed point **520,** only one matching circuit **274** is needed for matching one of the filters. Such arrangement provides additional benefits.

In the arrangement as shown in Figures 4a and 4b, all the upper band Rx and Tx paths are separated. The upper band Rx paths are connected to the antenna **20,** while the upper band Tx paths are connected to the antenna **10.** As such, the Rx and Tx antennas **10, 20** can be unbalanced antennas, with each antenna in a separate module. Furthermore, each module has three filters for the upper band that are matched to one single feed point with one matching element. As with the switching elements **48, 46, 82** in Figure 2a, the matching elements in Figure 4a can be replaced by CMOS or p-HEMT switches **76, 78,** as shown in Figure 4c. As such, only one 2GHz Tx filter **34,** and one W-CDMA tx filter **346** are necessary. The switch in the Tx paths needs to be extremely linear.

The separate antennas for the Rx and Tx paths provide some "for free" Tx to Rx attenuation. The term "for free" in this context means that, in order to have more than one

antenna that are not too much influenced by each other (loading conditions at antenna port etc), there must be a certain amount of isolation between the antennas, typically 10 dB being a minimum requirement. This is the case even in the conventional GSM vs W-CDMA antenna arrangement. This means that, with a proper Rx and Tx arrangement, the 10 to 20dB of isolation can be used to attain some of the required Tx to Rx isolation as well. This results in some relaxation in the duplexing requirements. Furthermore, the Rx antenna **20** can now be optimized for omni-directionality. Likewise, the upper band Tx antenna **10** can be optimized to achieve as low SAR (specific absorption rate) as possible for low radiation mobile phones. Moreover, because the impedance level of the Rx chain is typically higher than that of the Tx counterpart, the antenna impedance can be designed to suit the upper band Rx and upper band Tx only, when the Rx and Tx chains are connected to different antennas.

The methods as discussed above can be used in a front-end engine for U.S. current or future W-CDMA frequencies, or in a front-end engine having mixed use of European and U.S. W-CDMA frequencies. More particularly, the present invention is applicable to any given set of at least three frequency bands that are close, but not overlapping in frequency. For example, the 2GHz GSM Tx path **260** as shown in Figure 4a can also be used for the current U.S. W-CDMA (US1, Tx 1850-1910 MHz) and the new U.S. W-CDMA (US2, Tx 1710-1755 MHz). These modes share the same antenna **10** with the EU W-CDMA Tx path **340**. Likewise, the 1900GSM Rx path **240** as shown in Figure 4b can also used for the current U.S. W-CDMA (US1, Rx 1930-1990 MHz), and the European W-CDMA Rx path **320** can also be used for the new U.S. W-CDMA (US2, Rx 2110-2155MHz). It should be noted that the W-CDMA US2 Rx has a smaller bandwidth than the European counterpart (2110-2170MHz). Furthermore, not all of the GSM and W-CDMA bands have to be implemented on a Tx/Rx system. In order to accommodate different W-CDMA standards, the relevant filters must be designed to have different passband frequencies.

Figure 4d shows a different embodiment of the 2GHz Rx module as shown in Figure 4b. The filters **226**, **246** and **326** in these different embodiments are either fully balanced and each is associated with a balun in front thereof, or each of filters has a single to balanced function included therein (acoustic balun). This applies to all Balun/Filter combinations. As shown in Figure 4d, the balun and the filter in each path are integrated into a filter that includes the single to balanced transformation. The filters that have the

single to balanced transformation in the Rx paths **220**, **240** and **320** are denoted by reference numerals **228**, **248** and **328**, respectively.

In Figure 4a, the frequency separation between the signal path **340** (1920 MHz - 1980 MHz) and the signal path **260** (1850 MHz - 1910 MHz) in the same module **4** is only 10 MHz, rendering the matching of filters **346** and **268** difficult. It is thus preferable to remove the transmission signal path for the 1850 - 1910 MHz to module **8** of Figure 4b, and to move the signal path **220** in module **8** to module **4**, as shown in Figure 4e and 4f. As such, the smallest frequency separation between any two bands in the same module is 20 MHz. In Figure 4f, the smallest frequency separation occurs between signal path **260b** (1850 - 1910 MHz) and signal path **240** (1930 - 1990 MHz). In Figure 4e, the smallest frequency separation occurs between signal path **220** (1805 - 1880 MHz) and signal path **340** (1920 - 1980 MHz). In Figures 4e and 4f, items **281** - **285** are matching circuits, which can be coils, capacitors, transmission lines or the like. Items **226, 246, 266, 268, 326** and **346** are selective bandpass filters.

With three filters in one Rx module, as shown in Figures 4b and 4d, only the filter with the frequency that lies between the lowest and the highest frequency bands needs a matching circuit, which can be typically implemented with one capacitor and one or more inductors. The matching can also be carried out using striplines or different arrangements of coils and capacitors. The matching of at least three filters to a single point is generally possible if the frequency separation among these filters is not too small (the matching with a frequency separation of 1GHz or 2GHz is straightforward). The limit of the frequency separation depends on the filter technology and selectivity requirements, but a typical minimum is around 1% of the center frequency (i.e. filters close to 2GHz, for example the GSM 1800 and 1900, W-CDMA 2110 Rx filters, are possible to match since the separation between the upper passband edge of 1800 and the lower edge of 1900 have a separation of 50MHz and a larger separation to the W-CDMA Rx). In particular, the separation should be >20MHz for technologies realizable at this point in time. In the above example, the three different frequency ranges are 1805-1880MHz, 1930-1990MHz and 2110-2170MHz.

The separation of Rx and Tx antennas in the upper bands together with the steep Rx filters provides sufficient Tx to Rx isolation to render any additional Tx/Rx switching unnecessary. Furthermore, it is possible to design the filters so that they are selective enough to achieve Tx to Rx isolation. However, the problem of cross band isolation

remains to be solved. This problem arises from the fact that even though the Tx and Rx bands of a given standard do not overlap, there may be, in a multiband engine, overlapping between Tx frequencies of one standard and Rx frequencies of another standard. For example the 1900GSM standard has its Tx mode at 1850-1910MHz and the corresponding Rx mode at 1930-1990MHz (thereby having a separation of 20MHz). The Tx mode does partially overlap with the 1800GSM Rx, which is operated at 1805-1880MHz. This means that even when the signal from the Tx antenna is correctly attenuated in the 1900GSM Rx filter, the signal is able to pass trough the 1800GMS Rx filter. From the system point of view this is problematic because the next element in the Rx chain is usually an LNA (low noise amplifier), which is already integrated on to an RF-ASIC. Even though the LNA for the 1800GSM would be in the OFF state, sufficiently high signal levels may exist at the input to the RF-ASIC die, e.g. the bondwires, causing interference in the operation of the RF-ASIC. This is especially true for modern RF-ASIC that operates on very low supply voltages like 1.2V. In such a case, a high level input signal may even damage the RF-ASIC itself. Moreover, the only attenuation in these cross band situations is provided by the separate antennas and is about 10-15dB. This attenuation is not enough. These potential cross band frequencies are shown in Figures 5a and 5b for the case involving 1800GSM, 1900GSM and the European W-CDMA.

As shown in Figure 5a, the upper band Tx chain connected to the antenna **10** includes 1800GSM Tx_3 (1710-1785MHz): 1900GSM Tx_4 (1850-1910MHz) and W-CDMA (EU) Tx_7 (1920-1980MHz), and the upper band Rx chain connected to the antenna **20** includes 1800GSM Rx_3 (1805-1880MHz), 1900GSM Rx_4 (1930-1990MHz) and W-CDMA (EU) Rx_7 (2110-2170MHz). Thus, the frequency overlap in these chains is: Tx_4 - Rx_3 (30MHz, from 1850 to 1880MHz), and Tx_7 - Rx_4 (50MHz, from 1930 to 1980MHz). The cross band problems are also illustrated in Figure 5b. If the maximum output power at the antenna in Tx mode is 30 to 33dBm (depending on system standard) and a typical isolation that can be achieved between two separate antennas is between 10 to 20dBm, for example, then the power level at the Rx antenna is from 13 to 23dBm. In such a case, the antennas do provide some free Tx to Rx isolation, but for the crossband this is not sufficient, since a typically acceptable maximum power level at the Rf-ASIC input (Rx path) is around 0dBm during Tx time slot (i.e. LNAs in ASIC are off). Therefore, some means of providing additional attenuation in these cross band cases is needed.

Sufficient cross band isolation can be achieved in a multiband engine by basically two methods: either implementing switching in the Rx paths that are problematic, or moving some or all of the LNAs from the ASIC to the Rx module. The switches provide adequate increase in isolation, but also increase the insertion loss (the switches can have different arrangement, e.g. in shunt to ground). Cross-band isolation in the 2GHz Rx module using switches is shown in Figure 6a. For example, a PIN diode **50** is used as a switch in the 1800GSM Rx path **220** such that the PIN diode **50** is switched off when the 1900GSM Tx mode is used in order to provide good isolation to the 1800GSM Rx path **220**. Likewise, a PIN diode **52** is used as a switch in the 1900GSM Rx path **240** such that the PIN diode **52** is switched off when the European W-CDMA Tx mode is used in order to provide good isolation to the 1900GSM Rx path **240**. The PIN is only an example of how the switching could be performed. MEMS, CMOS and p-HEMT and the like are also possible. As shown in Figure 6a, the passive elements including the baluns **232, 252, 332,** the matching element **274** and the switches **50, 52** can be integrated into a sub-module **610.** The filters **226, 246** and **326** are separately fabricated as discrete sub-modules **620, 622** and **624.** All these sub-modules can be assembled into an Rx module **600.**

The LNAs method can, in principle, provide this isolation as a bonus, since an unbiased (=OFF) LNA has very good isolation (from input to output) and hence the signal level at the output of a LNA in the OFF state is small enough for the RF-ASIC. Moving the LNAs out from the RF-ASIC to the filter module also has several other benefits that are discussed later.

Cross-band isolation using LNAs is shown in Figure 6b. As shown, three low noise amplifiers **224, 244** and **324** are used, respectively, in the 1800GSM Rx path **220,** 1900GSM Rx path **240** and W-CDMA Rx path **320.** The low noise amplifiers **224, 244** and **324** are integrated in a sub-module **630.** The passive elements including the baluns **232, 252, 332** and the matching element **274** are integrated into a sub-module **612.** The filters **226, 246** and **326** are separately fabricated as discrete sub-modules **620, 622** and **624.** All these sub-modules can be assembled into an Rx module **601.** When operating at 1900GSM Rx mode, only the LNA **244** is ON, and the 1800GSM LNA **224** is OFF in order to provide necessary isolation. Similarly, when operating at W-CDMA (EU or US2) with the Rx path **320,** only the LNA **324** is ON. The 1900GSM LNA **244** is OFF. The advantages of such an arrangement include that the LNA at the OFF-state provides isolation "for free" and it works as a switch, and that the matching between the filters and

the LNAs can be designed to achieve optimal performances. It should be noted that only the bipolar process is required for the low noise amplifiers. An RF-ASIC can be made of CMOS.

If the baluns in the Rx modules are not acoustic baluns, as those shown in Figures 4d,
6a and 6b, they can be integrated with passive matching elements on e.g. very small silicon, other semiconductor or glass chips. It should be noted that the 1900GSM Rx path **240** is also used for the current U.S. W-CDMA (US1) Rx mode, and the European W-CDMA Rx path **320** is also used for the new U.S. W-CDMA (US2) Rx mode. As such, the receive module is a single-antenna module in a "WORLD" W-CDMA EU/US2/US1 and 1800/1900GSM Rx combination.

An additional benefit of separating the upper band RX and Tx is that the front-end architecture is well suited to support Rx-MIMO/diversity functionality.

In a MIMO receive module, at least two of the signal paths connected to two different antennas are used simultaneously to receive signals of the same mode in the same frequency band. For example, in the W-CDMA EU/US2 MIMO and 1800GSM Rx combination, the W-CDMA EU/US2 paths **320** are separately connected to two antennas. The second antenna is also matched to the 1800GSM Rx path **220**.

In diversity, the only requirement is the duplicating of the module, or one or more signal paths. For example, two identical Rx modules can be used side-by-side, as shown in Figure 7. In such case, only one Tx module (Figure 4a or Figure 4c, for example) is necessary.

In the modules that contain upper band Tx paths, such as 1800 & 1900GSM Tx paths **260** and/or W-CDMA (EU) Tx path **340**, the 1800GSM Tx band and the 1900GSM Tx band, in most cases, are provided from one common power amplifier (PA). Thus, the Tx filtering of the upper band GSM Tx path can be done with one harmonic filter, such as filter **34** in Figure 2a, that has a wide enough passband to cover both GSM Tx bands. Alternatively, Tx filtering is achieved by using two passband filters, such as filters **266, 268** in Figures 3 and 4a, that are matched to each other at both the output end and the input end. The W-CDMA Tx path **340** requires a separate filter, such as passband filter **346** in Figure 4a. Any of the harmonic filter **34**, passband filters **266, 268** and **346** can be a balanced filter, or a filter that performs a single to balance transformation, depending on whether any of the power amplifiers has a differential output.

The 1GHz GSM bands **110, 130, 150** are either connected to the Tx or the Rx antenna using a conventional antenna switch approach. That is, one of the antennas has to be designed such that it also has a resonance at 1GHz. The main reason for this is that the 1GHz antenna is the largest one and it is seen, therefore, as not feasible to have separate Tx and Rx antennas for the lower bands.

The advantages of this invention are many (some may depend on the specific band combination and implementation):

- The reduction of number of switches: lower insertion loss, less control lines, smaller current consumption (*one* PIN diode draws from 4 to 10mA of current). Switch associated bias components reduction
- Separate Rx and Tx antennas: for free Tx to Rx isolation, less stringent filtering requirements (especially in CDMA applications), smaller number of components.
- LNAs in the Rx module (or on the module, where the Rx filters are): OFF-state LNA provides for free cross band isolation (no need for switches), matching between the filters and LNA can be designed ideally with no unknown factors from various engine board designs (routing etc), only bi-polar needed, system level noise figure in most cases improved and has less variation, in MIMO applications the whole Rx module can be duplicated and due to LNAs in the module even longer connections to RF-ASIC cause only small variations in noise figure and gain (equal noise figure in the different Rx-branches is important in a MIMO receiver).
- Modules having common footprint, I/O allocation may be used with only the internal die selected at the module manufacturing stage, depending on the build required.
- The filtering of GSM Tx with truly selective filters obviate the need for switches, since at least three filters with no over lap in frequency can be matched to one single feed point.
- The Rx antenna **20** can be optimized for omni-directionality, whilst the upper band Tx antenna **10** can be optimized to achieve as low SAR (specific absorption rate) as possible for low radiation from the mobile terminal.

It should be noted that the W-CDMA modes as described above are related to W-CDMA EU/US1/US2. However, the present invention is also applicable to all other W-CDMA modes presently existing and those to be developed in the future, so long as they are operated substantially the same frequency ranges.

Thus, although the invention has been described with respect to a preferred embodiment thereof, it will be understood by those skilled in the art that the foregoing and various other changes, omissions and deviations in the form and detail thereof may be made without departing from the scope of this invention.